DOI: 10.24850/j-tyca-14-05-07

Articles

Water quality in urban rivers: Fucha River case, Bogotá, Colombia

Calidad del agua en ríos urbanos: caso del río Fucha, Bogotá, Colombia

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Abstract

Bogota is the capital city of Colombia, which has four bodies of water that cross it from east to west, the Fucha River being a neighbor of UNAD, for which reason the COBIDES research group, from UNAD, planned a set of methodological activities to know the water quality of section three of the Fucha River based on the General Quality Index for Surface Waters ICACOSU, concerning the fulfillment of Resolution 5731 of 2008, which specifies the water quality objectives for the city. To fulfill the objective of the research detailed bibliographic review of the study area was carried out, six (6) water measurement points were determined considered: representativeness, accessibility, and safety of the location. Once the results were obtained by the laboratory, the necessary calculations and analyzes were carried out to establish the ICACOSU of 5 and 7 variables and the results of the sampling were compared with the quality objectives established by Resolution 5731 of 2008; thus, it follows that the water quality of the Fucha River for the ICACOSU of seven variables is very bad. Due to the concentration of fecal coliforms, so it is not suitable to establish the biological balance of self-purification on its way to the Bogotá River mouth, about quality objectives, they are only met in two monitoring points with a compliance value of less than 85 %.

Keywords: ICACOSU, dumping, monitoring, quality objectives, pollutant load, parameter.

Resumen

Bogotá es la capital de Colombia y cuenta con cuatro ríos que la atraviesan de oriente a occidente: Tunjuelito, Fucha, Salitre y Torca, los cuales se han subdivido en cuatro tramos para su estudio, por lo que se planificó la metodología para conocer la calidad hídrica del tramo 3 del río Fucha con base en el Índice de Calidad General para Aguas Superficiales (ICACOSU), en relación con el cumplimiento de los objetivos de calidad hídrica establecidos en la Resolución 5731 de 2008 para los ríos de la ciudad. Para dar cumplimiento al objeto de investigación, se realizó una revisión bibliográfica de la zona de estudio; se determinaron seis puntos de medición hídrica de los parámetros: OD, SST, DQO, CE, pH, CT, DBO y Q, teniendo en cuenta representatividad y accesibilidad. Obtenidos los resultados del laboratorio se hicieron los cálculos y el análisis para establecer el ICACOSU de 5 y 7 variables, y comparar los resultados de los parámetros con los objetivos de calidad hídrica establecidos para el río Fucha. Se deduce que la calidad del río Fucha para el ICACOSU de siete variables es muy malo para los puntos de monitoreo 5 y 6, por la disminución en la concentración de OD (0.35 y 0.17 mg/l O_2, respectivamente) y el aumento de la concentración de DBO_5 en el punto de monitoreo 6 (112 mg/l O_2); sólo los puntos de monitoreo 2 y 3 cumplen con un valor superior al 50 % en el cumplimiento de los objetivos de calidad hídrica.

Palabras clave: ICACOSU, vertimientos, monitoreo, objetivos de calidad, carga contaminante, parámetro.

Received: 26/02/2021

Accepted: 17/03/2022

Introduction

Urban water resource management is becoming increasingly important in capital cities, and Bogotá D.C. is no exception, since urban rivers are part of the environmental balance of the city, they facilitate a large part of the drainage of wastewater from the city and protect it from possible flooding, receiving runoff generated by rain and providing habitat for different native or migrant species; in many cases, rivers are not only used to satisfy the demand for consumption, but are also a source of social development, as human relations of coexistence and economic advancement are generated around them (CAR, 2011).

The city of Bogotá D.C. has 7 181 469 inhabitants (DANE, 2020) and is administratively divided into 20 localities to offer public service networks; it is in turn subdivided into 117 Zonal Planning Units (UPZ), in order to define and specify the planning of urban land, responding to the productive dynamics of the city (Mayor's Office of Bogota, 2004). The city is crossed from east to west by four urban rivers (Tunjuelito, Fucha, Salitre and Torca) that feed the Bogotá river basin, a body of water of national interest due to its state of degradation. Furthermore, the Bogotá River flows into the Magdalena River, one of the most important rivers in the country, which crosses it from south to north, and its basin is responsible for about 80 % of Colombia's GDP (The Nature Conservancy, 2019).

The Fucha River, with a length of 17.30 km and a total drainage area of 17 536 ha, originates in the Andes mountain range, as a result of the confluence of the La Osa and Upata streams (SDA, 2015). The river is divided into four sections located at the following coordinates: Section one (1) with initial position at 4°33'31.29¨N - 74°03'42.97¨W; Section two (2) with initial position at 4°34'51.64¨N - 74°5'25. 10¨W; Section three (3) with initial position at 4°36'22.24¨N - 74°7'8.68¨W and finally section four (4) with initial position at 4°38'51.04¨N - 74°7'41.41¨W flowing into the Bogotá River at the final position 4°39'44.7 "N 74°09'33.5 "W (see Figure 1) (Pérez & Zamora, 2015).

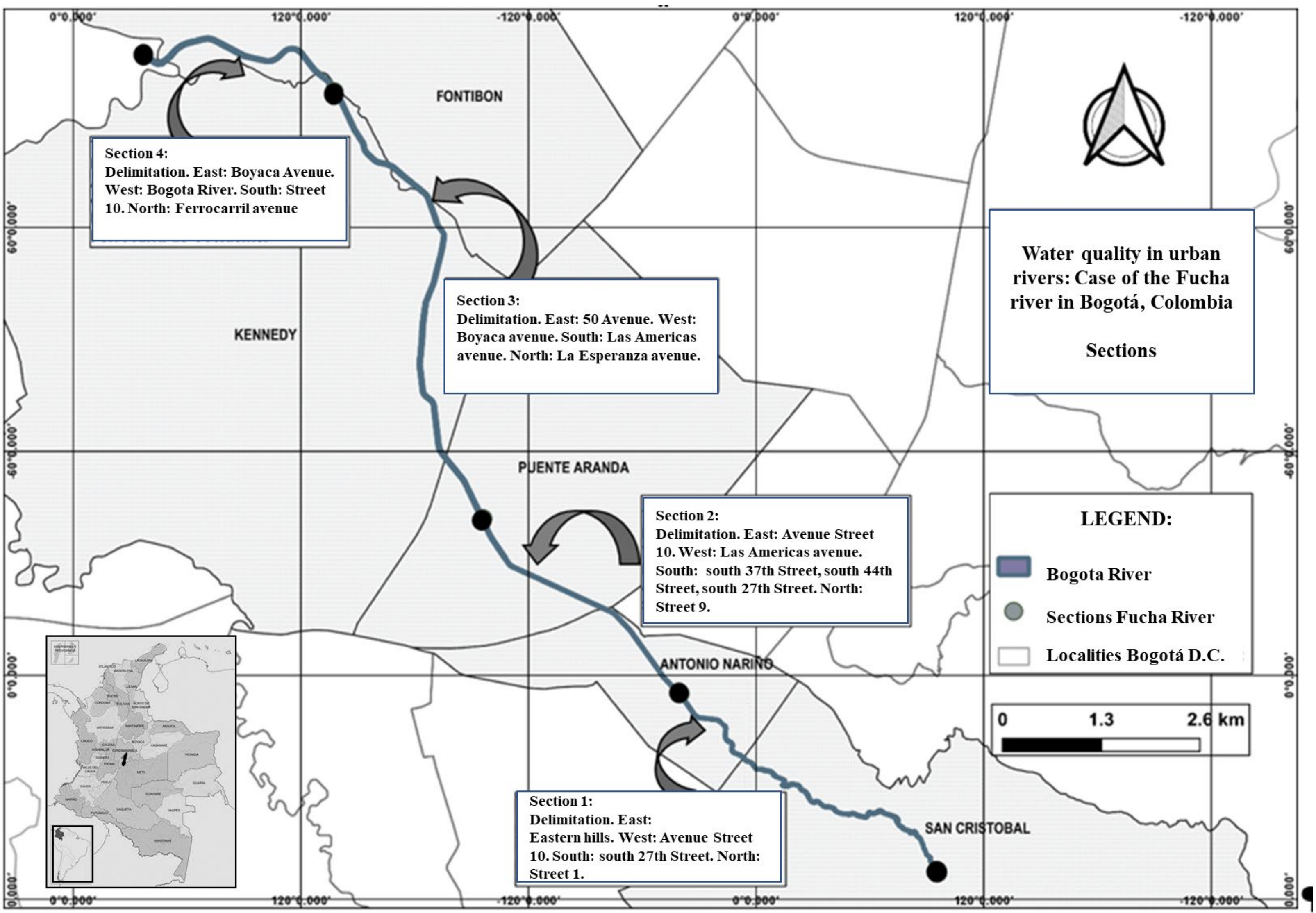

Figure 1. Map of the Fucha River, Bogotá D.C.

The competent environmental authority in the city of Bogota is the District Secretariat of the Environment (District Secretariat of Environment -SDA), which since 2006 sets water quality objectives for the Fucha River for 4 and 8 years, and was last updated in 2015 by

Resolution 3116. Likewise, the Bogota Water Quality Network (RCHB), through agreement 005 of 2006 between the Bogota Water and Sewerage Company (EAAB) and the SDA, implemented monitoring points for all the city's river basins, with 6 points distributed in the 4 sections of the Fucha River.

It is clear that the use of measurements and calculation of indicators allow environmental authorities to make decisions, as confirmed by Romanelli and Massone (2016) when mentioning that environmental indicators represent a useful tool to organize, systematize, quantify, simplify and communicate information related to environmental aspects, which is basic for decision making in the framework of environmental management. Likewise, Peña-Guzmán, Melgarejo-Moreno y Prats-Rico (2016) argue that knowing the components and behavior of the urban water cycle allows to properly managing the environmental and economic resources of a city.

The water quality of the Fucha River changes in less than 9 kilometers as it leaves the El Delirio nature reserve and crosses the city. At kilometer 2 it is channeled, at kilometer 3 it is surrounded by residential areas, and at kilometer 7 it meets the Puente Aranda industrial area, where it receives discharges with a high pollution load, and ceases to be a river and becomes a sewage channel until it flows into the Bogotá River (Alcaldía Local de Puente Aranda, 2016).

The goal of this study is to identify the water quality in section three (3) of the Fucha River by calculating the ICACOSU in order to determine compliance with the objectives established in Resolution No. 5731 of 2008 by the SDA in the city of Bogota D.C. (SDA, 2008a).

Compliance with the quality objectives set forth in Resolution No. 5731 of 2008 is a challenge, which entails continuous monitoring of the industries that discharge into the river, the possible implementation of water treatment projects in the riverbed and the awareness of citizens regarding this local problem with regional impact (SDA, 2008a; SDA, 2008b).

In this sense, in 2010 the country generated the policy for the Integral Management of Water Resources, which was designed for a period of 12 years (2010 -2022) through the development of six specific goals: supply, demand, quality, risk, institutional strengthening and governance (Múnera, 2015). Among the technical instruments for Integrated Water Resource Management are the Water Resource Management Plan (MinAmbiente, 2014), which guides and provides technical support to address and apply other instruments, such as: regulation and discharge permits, sanitation and discharge management plans, water concessions, water use regulations, and programs for efficient water use and savings (MinAmbiente, 2014).

Water quality worldwide is a problem faced by many governments in the world, according to UNESCO in its world report on the "Development of water resources" states that water quality is an indicator of health in the population, the factors that affect the quality of water are the following: water quality and basic sanitation are part of the human rights recognized by the United Nations, therefore, it is the duty of the leaders

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

to guarantee these rights to the population, as well as a duty to maintain and preserve water resources worldwide.

Materials and methods

The research group determined the Index of General Quality in Surface Streams (ICACOSU) for 5 variables (dissolved oxygen - DO, total suspended solids - TSS, chemical oxygen demand - COD, electrical conductivity - EC and pH) and 7 variables (DO, TSS, COD, EC, pH, total coliforms - TC and biological oxygen demand - BOD_5) and analyzed the status of compliance with the quality objectives with respect to Resolution 5731 of 2008, for which reliable sources were reviewed to justify the problem, determined the variables to be analyzed with respect to the current conditions of the Fucha River. The research group also conducted a reconnaissance of section 3 of the river to demonstrate and locate the main discharge points, performed a sampling with a laboratory accredited by the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) at six strategic points during the September 2020 dry season to calculate the index and compare the results to establish compliance with water quality objectives.

The methodology used was basically divided into three phases: reconnaissance of the study area, sample collection and calculation of the ICACOSU, as described in Figure 2.

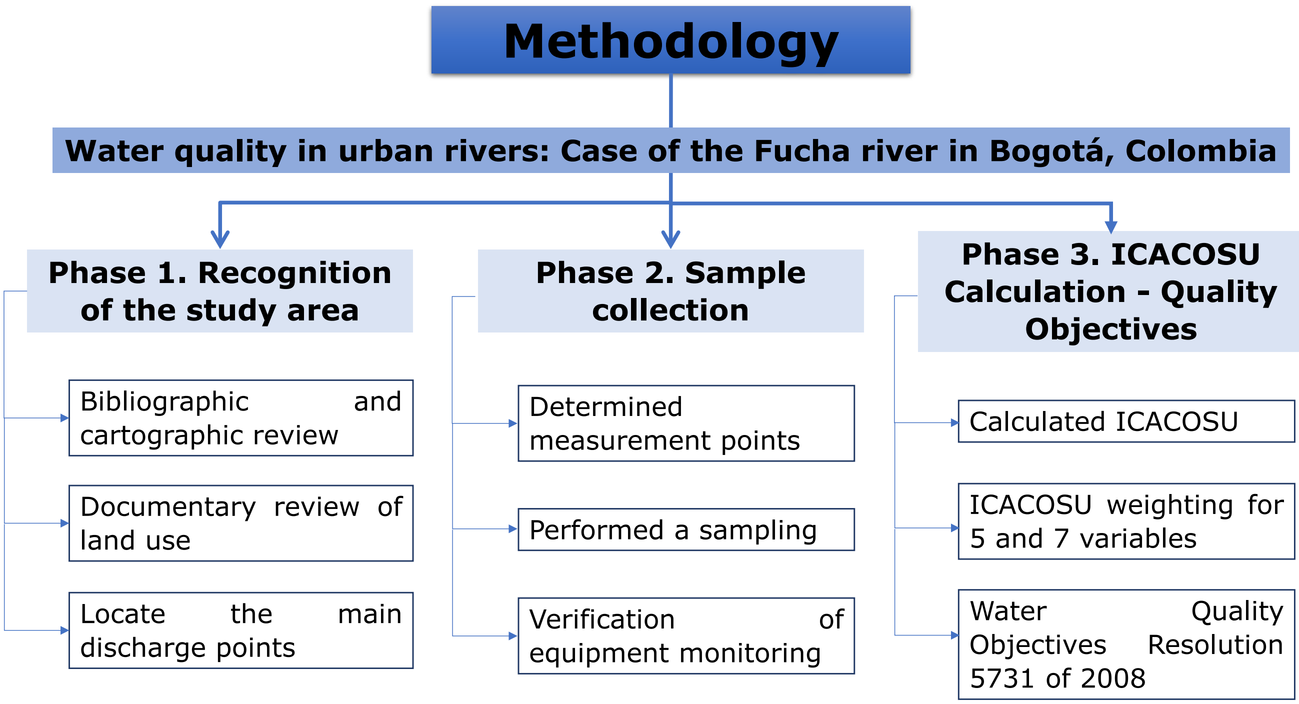

Figure 2. Methodology used

Phase 1. Recognition of the study area

The study area is section 3 of the Fucha River that extends from the initial position at 4°36´22.24¨N - 74°7´8.68¨W and has a length of 4.89 km, during this route it crosses 3 localities and 5 UPZs (see Figure 3) (SDP, 2015). The first locality with which the river has contact is #16 Puente Aranda, in which land use is distributed as follows: residential: 38.68 %; industry: 12.70 %; endowment: 8.96 %; trade 7.96 %; services: 21.64 % and others: 10.06 % (SDP, 2012); there is encroachment into the river's banks and the river's Environmental Management and Preservation

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Zone (ZMPA) by industries and parking lots that generate discharges. There are discharges due to the interception of the Comuneros and San Francisco canals, which collect rainwater and wastewater (SDP, 2015).

No	Point identification	Coordinates		Discharge margin	Impact
		Latitude	Longitude		
1	Cruce Carrera 51 – Fucha River	4,6072555	-74,1188988	South	High
2	Cruce Transversal 52- Fucha River	4,6095254	-74,1202943	North	Low
3	Cruce Transversal 52ª bis- Fucha River	4,6107096	-74,1204617	North	Medium
4	Cruce Transversal 53- Fucha River	4,6119387	-74,1218088	South	High
5	Cruce Transversal 53a- Fucha River	4,613125	-74,1223793	North	Low
6	Cruce Transversal 53g- Fucha River	4,6134814	-74,1230718	North	Low
7	Cruce Transversal 55- Fucha River	4,6154311	-74,1241382	North	Low
8	Cruce Transversal 55- Fucha River	4,6152107	-74,1240697	South	Low
9	Cruce Transversal 57- Fucha River	4,615931	-74,1236163	North	Low
10	Cruce Transversal 57- Fucha River	4,6170572	-74,1240274	South	Low
11	Cruce Transversal 64- Fucha River	4,619865	-74,1247002	North	Medium
12	Antes de Cruce Carrera 68- Fucha River	4,6200194	-74,1246334	North	High
13	Después Cruce Carrera 68- Fucha River	4,6204453	-74,1249755	North	Medium
14	Después Cruce Carrera 68- Fucha River	4,6206903	-74,125271	South	Medium
15	Cruce Calle 2 - Fucha River	4,6219933	-74,1258881	South	Low
16	300 meters up water Cruce Avenida Calle 3 - Fucha River	4,6242526	-74,1264369	South	Low
17	Cruce Avenida Calle 3 - Fucha River	4,6242084	-74,1261992	North	Medium
18	Cruce Avenida Calle 3 - Fucha River	4,6246517	-74,1264424	South	Low
19	100 meters down water Cruce Avenida Calle 3 - Fucha River	4,6242084	-74,1261992	North	High
20	100 meters down water Cruce Avenida Calle 3 - Fucha River	4,6262351	-74,1268837	South	Low
21	Cruce Avenida Calle 5ªbis - Fucha River	4,6277117	-74,1262649	South	Low
22	100 meters down water Cruce Avenida de las Américas - Fucha River	4,6297256	-74,1263114	North	High
23	Cruce Avenida Calle 9c - Fucha River	4,6337073	-74,1257506	North	Bajo
24	Cruce Avenida Calle 11 - Fucha River	4,6363703	-74,1250399	North	High
25	100 meters down water Cruce Avenida Calle 11 - Fucha River	4,6372146	-74,1247279	North	Low
26	300 meters down water Cruce Avenida Calle 11 - Fucha River	4,6377254	-74,1243945	North	Medium
27	Cruce Avenida Carera 69 - Fucha River	4,6412043	-74,1231413	North	High
28	100 meters up water Cruce Avenida Carrera 71d - Fucha River	4,6443194	-74,1245909	North	High
29	Cruce Avenida Carera 71f - Fucha River	4,6460238	-74,1261918	North	Low
30	100 meters up water Cruce Avenida Boyacá- Fucha River	4,6471078	-74,1273709	North	Medium

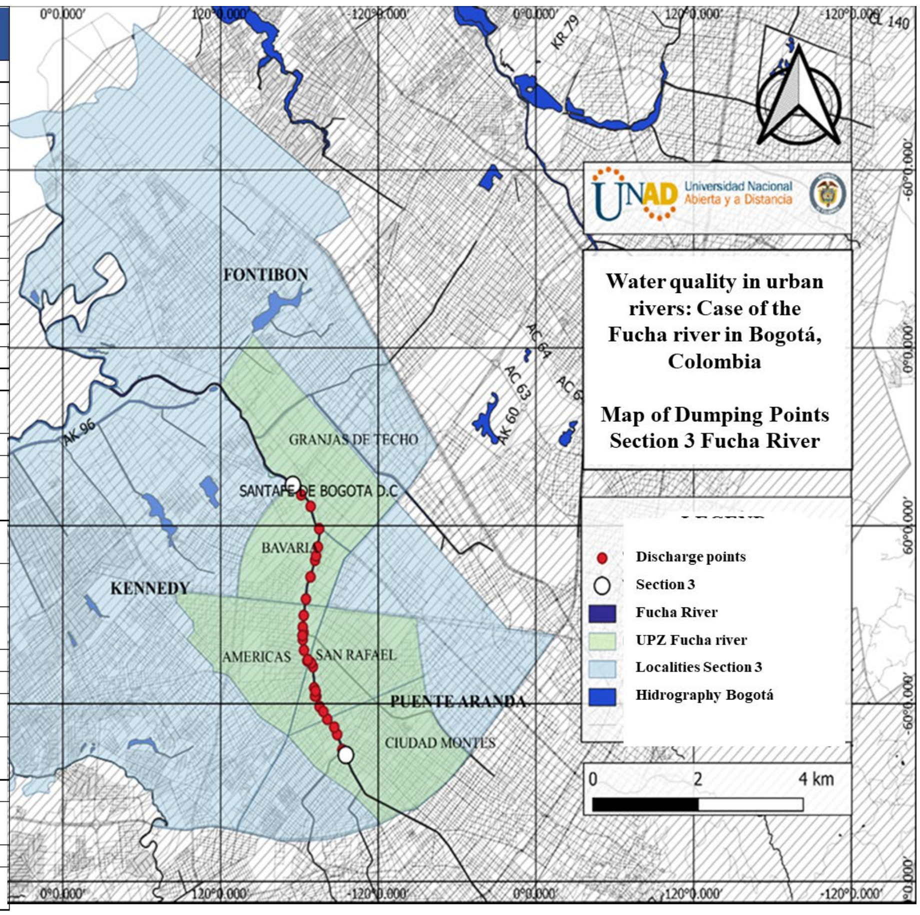

Figure 3. Map of Dumping Points Section 3 Fucha River (QGIS V. 3.0).

The two UPZs of locality #16 are 40. Ciudad Montes and 43. The territory of UPZ 40 has no undeveloped areas on urban land and has the largest protected area (27 ha) due to the location of the Ciudad Montes zonal park, part of the Fucha River canal and part of the Albina and Río Seco canals (Secretaría de Integración Social, 2016). At this point, the river receives the discharge of the Río Seco canal, a basin that drains domestic and industrial wastewater from the Rafael Uribe and Puente Aranda districts, water with foul odors, street dwellers and organic waste (Alcaldía Local de Puente Aranda, 2012).

UPZ 43, as defined in the Land Use Plan (POT), is a sector defined by the treatment of consolidation with moderate densification, which represents land that can be densified while respecting the existing urban characteristics (Secretaría de Integración Social, 2016). The POT defined activities as area of residential activity with economic activity in housing, area of industrial activity and area of commerce and services, agglomerate commerce zone (Secretaría de Integración Social, 2016). The local mayor's office (Alcaldía Local de Puente Aranda, 2012) reports that at the mouth of the Comuneros canal in the Fucha River, the water contains fecal coliforms and solid waste, due to the presence of street dwellers.

District #8 Kennedy is one of the most populated in the Capital District, its land use is: residential 40.49 %, industrial 2.48 %, commercial 24.04%, commercial 8.69 %, services 16.53 % and other 7.77% (Alcaldía Local de Kennedy, 2016). The main economic activities are centered on formal and informal commercial activity, with the presence of metal-mechanic and logistics industries and some food industries (SDA, 2017). The UPZs that are in contact with the river in locality #8 are 44 Americas and 113 Bavaria.

UPZ 44 is strategically located along specialized trunk corridors of the arterial road network, the POT defined as areas of activity: residential zone with commercial and service axes, zone with urban consolidation treatment, residential activity with economic activity in housing, zone with consolidation treatment with moderate densification.

UPZ 113 is divided into two sectors, one located to the east of the Fucha River canal, where industrial, business, commercial and service activities are concentrated, which are more closely related to the industrial zone of Puente Aranda. On the other hand, there is the zone located to the west of the Fucha River canal, which concentrates an important residential nucleus, with some commercial axes, mainly of local incidence. For UPZ 113, the POT defined the following activity areas: area of industrial activity industrial zone, area of commerce and services activity, area of large commercial areas, area of residential activity, delimited area of commerce and services, area of public services activity, area of collective facilities, and area of integral urban activity multiple activity zone (SDP, 2016).

The locality of #9 Fontibón is located in the western sector of Bogotá D.C. and is bordered to the south by locality #8 through the axis of the Fucha River and to the west by the Bogotá River and the municipalities of Funza and Mosquera. This locality has an area of urban land with the following uses: residential 26.42 %, industrial 5.75 %, commercial 4.15 %, commercial 10.28 %, services 17.73 % and other 35.66 % (SDP,

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

2016). UPZ 112 Granjas has access to the Fucha River in its predominantly industrial classification.

The geo information portal managed by EAAB and the Unified Enterprise Geographic Information System (SIGUE) were reviewed. The results show that the discharges of section 3 come from the city's storm and sanitary sewage system, since the Fucha River was designed to receive the domestic discharges of the households of the UPZs involved and also to conduct and receive the rainwater from the sector.

With the secondary and primary information collected, we proceeded to establish the 6 monitoring points (see Figure 4), with a distance of no more than 1 km between them; the accessibility to the point was also evaluated, agreeing on road bridge crossings for a fast and safe descent to the river, also, favoring the safety of the team, since the area suffers from problems of social inequality. Finally, sampling point #4 is performed at the same point established by EAAB and SDA (Agreement 005/2006) to monitor river quality in section 3 (SDA, 2008a).

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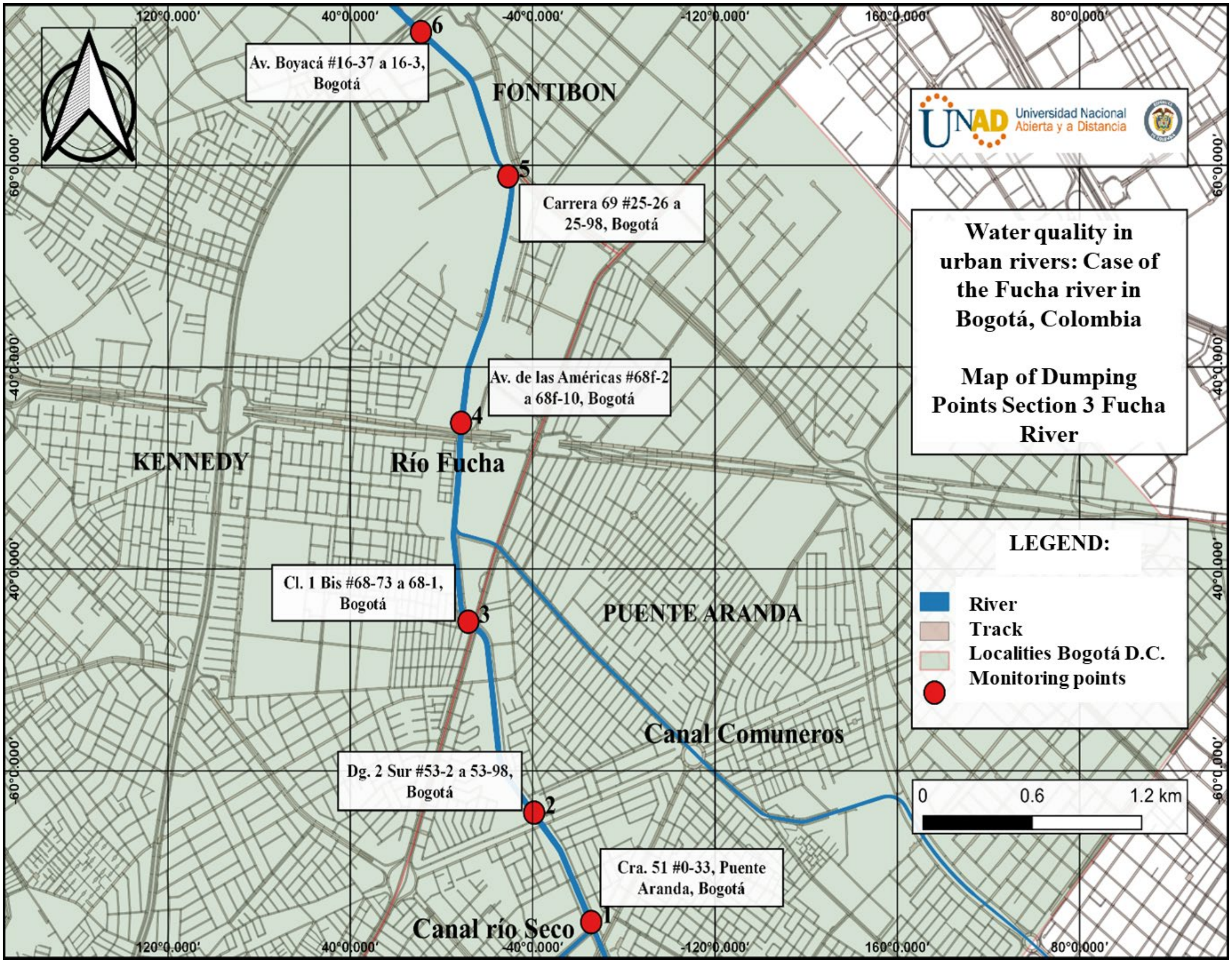

Figure 4. Sampling points in section 3 of the Fucha River (QGIS V. 3.0).

Phase 2. Sample collection

The "Standard Methods for the Examination of Water and Wastewater 23d Edition 2017" is the technical guide that defines the methodology to be used when water quality assessment is required. Table 1 describes the test techniques used in the study. According to the validations and/or confirmations carried out for each of the parameters in the laboratory both *in situ* and *ex situ*, the reliability of the results is guaranteed based on the limits of quantification shown in Table 1.

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Table 1. Test methods for sample analysis.

Test	Method	Reference	Measure	Units	Method quantification limit
Total Coliforms - TC	Enzymatic substrate - Multi-cell	SM 9223 B	*Ex situ*	NMP71000 ml	1.8
Biological Oxygen Demand - BOD5	Incubation 5 days and membrane electrode	SM 5210 B, 4500 - OG	*Ex situ*	mg/l O_2	2
Chemical oxygen demand - COD	Open backflow and titration	NTC-ISO 5667-10	*Ex situ*	mg/l O_2	10
Electrical conductivity - EC	Electrometry	SM 2510 B	*In situ*	µS/cm at 25°C	--
Dissolved oxygen - DO	Membrane electrode	SM 4500 – O G	*In situ*	mg/l O_2	--
pH	Electrometry	SM 4500 H+ B	*In Situ*	pH Units	--
Temperature - T	Thermometry	SM 2550 B	*In Situ*	°C	--
Total suspended solids - TSS	Gravimetry - drying at 105°C	SN 2540 D	*Ex situ*	mg/l	5

Source: Analquim Ltda. (Internal process) - 2020. Accreditation Resolution No. 0822 of August 06, 2019. IDEAM

In order to give reliability to the test methods, sample preservation techniques are required to delay physical, chemical and/or biological changes such as hydrolysis of compounds, adsorption effects, biological action, volatility of constituents, among others, that may occur after the sample is removed from the sampling site until its analysis in the laboratory. The preservatives listed in Table 2 were applied.

Table 1. Sample preservation.

Parameter	Container	Container volume (ml)	Number of containers	Sample type	Preservation
BOD_5 SST	Plastic bottle	2000	6	Point sample	Refrigeration ≤ 6 ºC without reaching the freezing point.
Total Coliforms	Sterile Clear Glass Bottle	230	6	Point sample	Refrigeration ≤ 6 ºC without reaching the freezing point.
COD	Narrow mouth amber glass bottle	500	6	Point sample	H_2SO_4

Source: Authors, Analquim Ltda. (Internal process), 2020.

The six point samples were collected on September 20 during the dry season, in the morning hours, complying with the established protocols, which represents the precise composition of the water for the given conditions.

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

Phase 3. ICACOSU Calculation - Quality Objectives

ICACOSU was the quality index selected to work with, which is calculated from concentration data of a set of 5 or 7 variables considered from the beginning, which largely determine the quality of surface waters. The ICACOSU quality index is formulated by IDEAM, it reduces large volumes of field data to a simple numerical value from zero (0) to one (1) and is classified according to water quality in ascending order in one of the following five categories: Very bad, Bad, Medium, Good and Excellent; which can be represented graphically by a color (IDEAM, 2013). The formula for calculating the index is given by:

Equation (1). ICACOSU calculation:

$$ICACOSU = \left(\sum_{i=l}^{n} W_I . I\right) \quad (1)$$

whereas:

WQI: Surface water quality index.

W_i: Weighting or relative weight assigned to the quality variable.

I: Calculated variable value.

n: Number of variables involved in the calculation of the index, dismissing from the measurement (IDEAM, 2013).

Equation (2). ICACOSU calculation by variables:

$$\mathrm{ICACOSU} = ICACOSU_{FA} * 0.8 + \mathrm{ILCAG} * 0.2 \quad (2)$$

Whereas:

ICACOSU: Water quality index for surface streams in general..

$ICACOSU_{FA}$: It is the aggregate index of physicochemical quality.

ILCAG: Environmental Capacity Index.

Equation (3). $\mathrm{ICACOSU_{FA}}$ calculation - 7 variables:

$$ICACOSU_{FA}: (Si_{OD} * 0.2) + (Si_{C} * 0.18) + (Si_{SST} * 0.15) + (Si_{DBO} * 0.15) + (Si_{DQO} * 0.12) + (Si_{COD} * 0.12) + (Si_{pH} * 0.08) \quad (3)$$

Equation (4). $\mathrm{ICACOSU_{FA}}$ calculation - 5 variables

$$ICACOSU_{FA}: (Si_{OD} * 0.2) + (Si_{SST} * 0.2) + \left(Si_{DQO} * 0.2\right) + (Si_{COD} * 0.2) + \left(Si_{pH} * 0.2\right) \quad (4)$$

Whereas:

Si_{OD}: DO saturation percentage sub-index

Si_{SST}: TSS subindex

Si_{DQO}: COD subindex

Si_{pH}: pH subindex

Si_{C}: TC subindex

Si_{DBO}: BOD subindex

Si_{COD}: EC subindex

The ILCAG is the lotic index of general environmental capacity, which corresponds to the logarithm of the average flow rate * 0.333.

Table 3 summarizes the variables that are involved in the calculation of the index for 5 and 7 variables, the unit of measurement in which each of them is recorded and the weighting they have in the calculation formula (IDEAM, 2013).

Table 2. ICACOSU weighting for 5 and 7 variables.

PARAMETERS AND WEIGHTINGS			
Variable	**Unit of measure**	**Weighting**	
		5 Variables	**7 Variables**
OD	% saturation	0.2	0.2
SST.	mg/l	0.2	0.15
DQO	mg/l	0.2	0.12
C.E.	µS/cm	0.2	0.12
pH	pH units	0.2	0.08
C.T.	NMP/1 000 ml	Not applicable	0.18
BOD	mg/l	Not applicable	0.15

Source: Centro de Investigaciones en Hidroinformática (2007).

The values obtained are summarized on a scale from 0 to 1 as shown in Table 4.

Table 3. ICACOSU Index.

FINAL CLASSIFICATION CATEGORIES ICACOSU-IDEAM		
Category	**Range**	**Color Scale**
Very bad	0-0.25	
Bad	0.26-0.50	
Average	0.51-0.70	
Good	0.71-0.90	
Excellent	0.91-1.0	

Source: IDEAM (2013).

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

Finally, the measured values were compared with resolution 5731 of 2008, a regulation that defines the maximum values that the Fucha River should be complying with as of 2018 (SDA, 2008b) (see Table 5).

Table 4. Water quality objectives.

10-year water quality objectives		
Parameter	**Unit**	**Value**
DO	mg/l	0.5
BOD_5	mg/l	60
COD	mg/l	180
TSS	mg/l	30
TC	NMP/100 ml	100 000
pH	Unit	6.5-8.5

Source: Resolution 5731 of 2008 (SDA, 2008b).

Results

The established monitoring points were verified with the field information collected in the four tours carried out, identifying the discharge points generated by the industries and residential areas that had a high, medium or low impact, depending on the degree of affectation to the river when

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entering. dumping, and that they were also repetitive during the visits made during the years 2019 and 2020, in order to select the number of samples to be taken and the specific points for the development of the monitoring.

The information was also contrasted with the Dumping Sanitation and Management Plan (PSMV) prepared by EAAB in 2006, which specifies 8 dumping points, and the field review coincided with 3 points described therein, dumping points 22, 25 and 30 (see Figure 4).

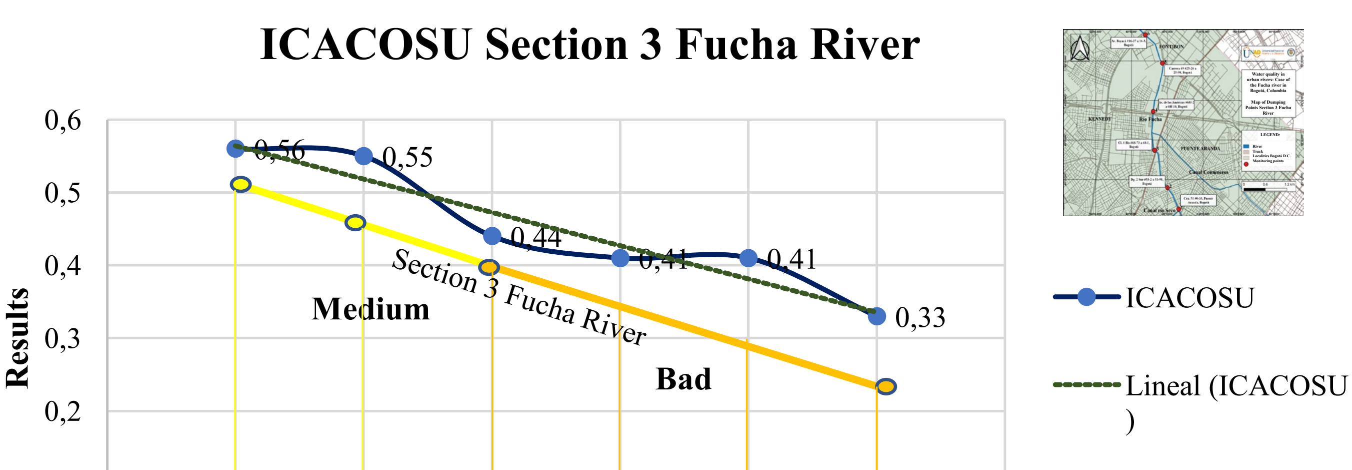
In the sampling carried out, nine physicochemical and microbiological parameters were measured at the six established monitoring points, as summarized in Table 6.

Table 6. Monitoring results.

Point	DO (mgO2/l)	TSS (mg/l)	BDO$_5$ (mgO2/l)	QDO (mgO2/l)	Conductivity (µS/cm a 25 °C)	pH	Temperature (°C)	Flow (l/s)	TC (NMP/100 ml)
1	3.31	32	72	140	176.6	7.6	13.5	1 888.21	150 000 000
2	2.29	25	42	76	209	7.6	14	1 380.93	496 000
3	1.53	28	54	100	269	7.6	14.6	2 002.82	181 900 000
4	0.63	50	78	164	350	7.8	17	1 702.21	9 060 000
5	0.35	52	59	108	400	7.8	19.5	2 158.76	66 700 000
6	0.17	69	112	136	547	8.2	21.1	2 022.36	95 900 000

Subsequently, based on the established methodology, the Water Quality Index (WQI) for the monitored surface water body is calculated. For water intended for human consumption, the ecological quality index can be used (Cerón-Vivas, Gamarra, Villamizar, Restrepo, & Arenas, 2019). To calculate the ICACOSU, each of the sub-indexes of the five parameters were obtained and multiplied by 0.2, which shows that the ICACOSU value is established as Medium for the first 2 points and Bad for the last 4 points.

This calculation is shown graphically in Figure 5, which shows the drop in the index from 0.56 to 0.33, mainly due to the decrease in DO from 3.31 mg/l to 0.17 mg/l and the increase in EC from 176 µS/cm to 547 µS/cm, between monitoring points #1 and #6.



Clasification ICACOSU	
Categorie	Range
Deficient	0 - 0,25
Bad	0,26 - 0,50
Medium	0,51 - 0,70
Good	0,71 - 0, 90
Excelent	0,91 - 1,00

Figure 5. ICACOSU result for five variables.

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

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The main difference between the ICACOSU index for 7 variables and the index for 5 variables is that it incorporates biological parameters: BOD_5 and TC and that the percentage weight distribution in each of the parameters is variable, with 68 % of the weighting remaining in four parameters: DO, TC, TSS and BOD_5. Figure 6 shows the behavior of the variables graphically.

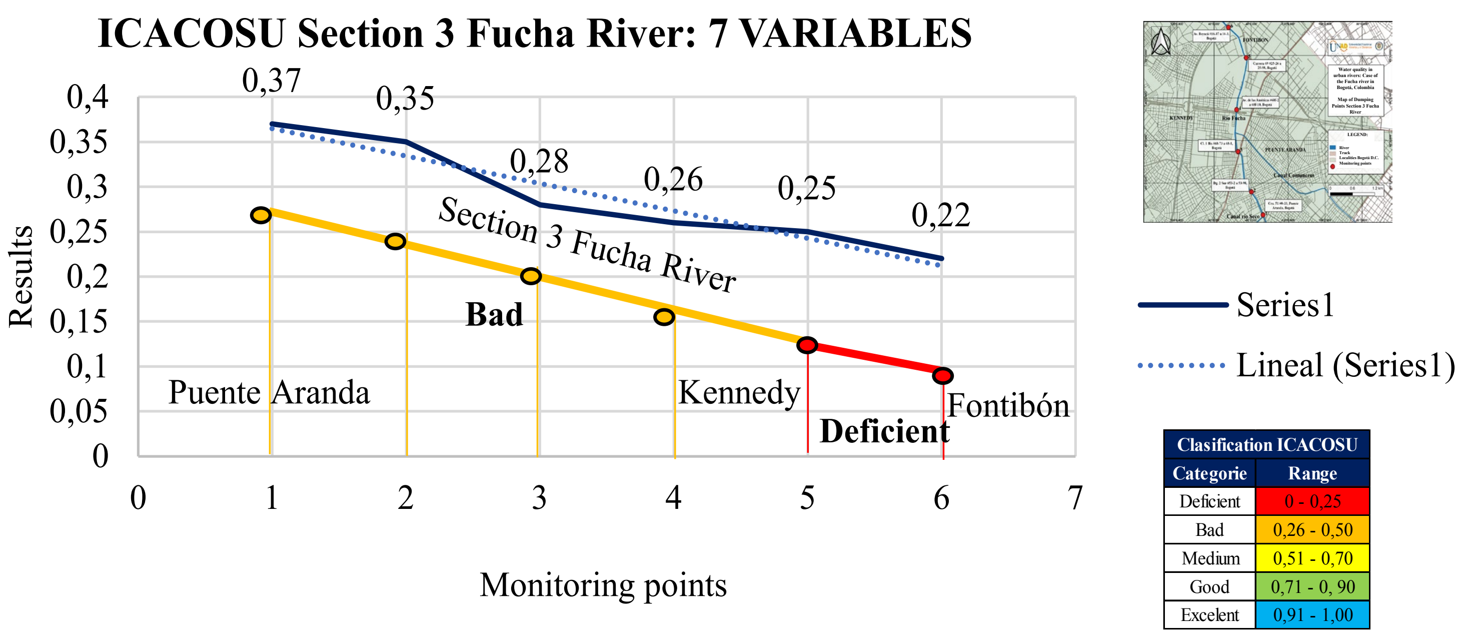

Figure 6. ICACOSU result for seven variables.

When performing the index assessment, the river quality goes from Bad to Very Bad, understanding that the BOD_5 variable increases from 72 mg/l to 112 mg/l in the river racking, between monitoring points #1 and

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

#6. Likewise, the TC concentration increases reaching its maximum value at monitoring point #3 with 1.82x1010 NMP/100 ml.

Comparing the variables against compliance with the quality objectives established for the Fucha River in section 3 that were to be met by 2018, it is evident that only two monitoring points are above 50 % compliance (monitoring points #2 and #3).

The TC value is not met at any of the monitoring points, the TSS value is only met at monitoring points #2 and #3, and the BOD_5 value is also met at monitoring point #5. The pH and COD values comply with the standard at all monitoring points (Figure 7).

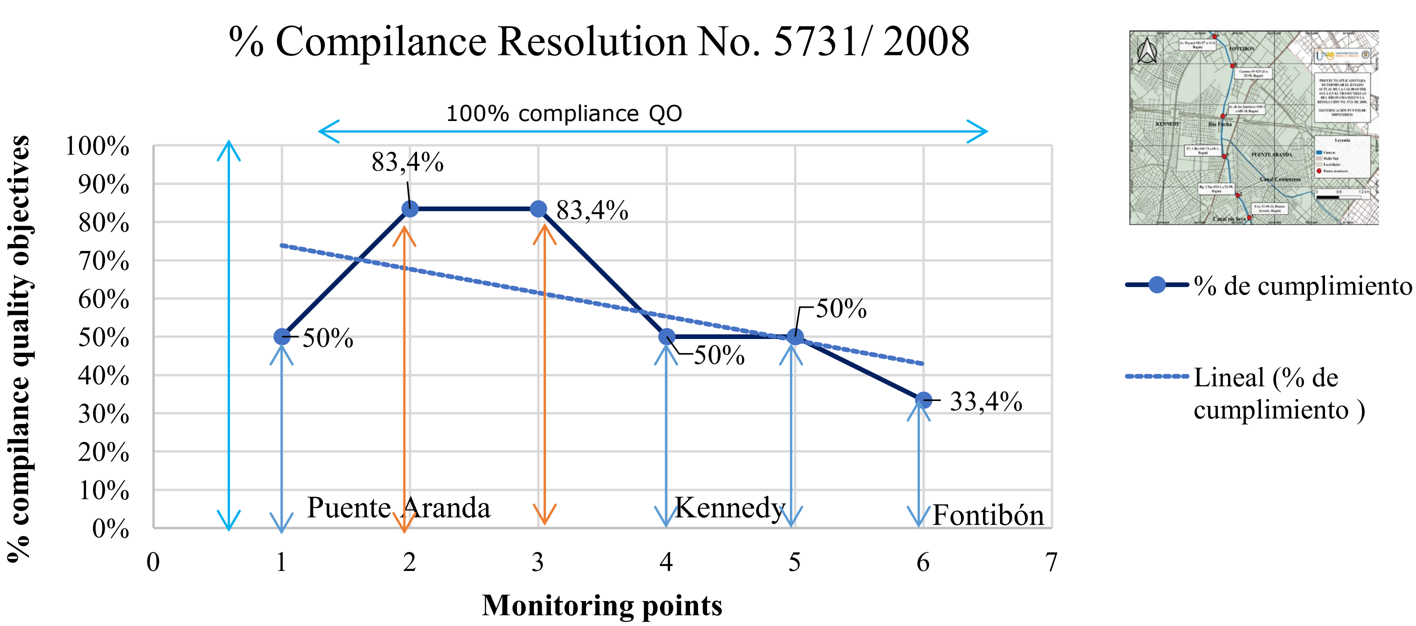

Figure 7. Results of compliance with quality objectives (Resolution 5731 of 2008) (SDA, 2008b).

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

Discussion

In relation to the ICACOSU of five variables, for the monitoring point with a value of ICACOSU: Medium, the high pollutant load entering from section 2 is highlighted. The discharge is mostly composed of domestic and industrial discharges from the Antonio Nariño and Rafael Uribe localities. It should be noted that the UPZ in which this point is located is urban with large green areas where the ZMPA is respected.

Monitoring point #2, ICACOSU assessment: Medium, parameters remain constant and tend to decrease in some concentrations (TSS, COD, BOD_5), at this point, there are no major generators of discharges. In this part of the section, the river bank is clean and discharges are limited to domestic and rainwater drainage. It is noteworthy that the DO and COD indicators are very low according to the U.S. EPA (Environmental Protection Agency), where it states in its report "Parameters of water quality – interpretation and standards" as a minimum concentration the value of 5 mg/l for DO and a minimum saturation percentage of 70 % to be able to establish some kind of natural balance or the possibility of the existence of captive life in the section.

Monitoring point #3, ICACOSU assessment: Bad, it is presumed that the pollutant load increases at this point due to the presence of street dwellers who work as primary waste collectors that sort the waste on the river banks and throw the disposable material into the river, so the TSS concentration increases by 11 %; industrial discharges begin to play a leading role with high inorganic matter content, increasing the EC (22 %) and chemical compounds sensitive to oxidation (COD increases by 24 %)

Monitoring point #4, ICACOSU assessment: Bad, it should be taken into account that it is the only point where the SDA in agreement with the EAAB (SDA, 2008a) performs water quality monitoring for section 3 of the Fucha River, at this point, industrial discharges are very evident with physicochemical, visual and organoleptic characteristics that reflect the pollutant load contributed to the river; parameters such as COD, TSS and EC increase their concentration by 39, 44 and 23 %, respectively, demonstrating that the discharges contain a large amount of inorganic matter, the presence of DO decreases by 60%, decreasing the possibility of improvements in its riverbed.

The water quality monitoring network at this point shows between 2016 and 2020 692 samples taken, in the monitoring of the Fucha River, in which on average the DO presents a value of 2.6 mg/l, BOD5 a value of 148.8 mg/l, COD 357.1 mg/l, TSS 109 mg/l and TC 4. 58E109 NMP/100 ml, also reports trace metals such as zinc (0.31 mg/l), cyanide (0.27 mg/l), manganese (0.09 mg/l), barium (0.08 mg/l), copper (0.07 mg/l) and total chromium (0.06 mg/l), among others, of public health interest, showing the impact of the industrial area and its discharges into the river.

Monitoring points #5 and #6, ICACOSU: Bad, as an effect of the discharges present in the last meters of section 3, at point #6 there is a percentage increase in its concentration in the EC (27 %), COD (47 %) and TSS (25 %) parameters, indicating that the characteristics of the river water become industrial type.

In 2016 Peña, Melgarejo and Prats with the values reported by the water quality monitoring network managed by the SDA calculated the CCME-WQI quality index. (Canadian Council of Minister of the Environment-Water Quality Index), which presents quantitative values between 0 and 100, divided into five ranges: excellent, good, fair, marginal and poor, the values obtained for the period from 2007 to 2013 for sections 1, 2 and 3 of the Fucha River were as follows: Section 1 went from Excellent to Good (100 - 88), Section 2 was always classified as Poor (34 - 41) and Section 3 was evaluated as Marginal in this time range (45 - 51).

This is how the deterioration of the river is evidenced and how it worsens considerably after point #3, since at this point the number of industrial discharges increases in addition to domestic discharges, making the possibility of self-purification more difficult as the river approaches its mouth.

For the analysis of the ICACOSU with respect to the 7 variables, it is evident that the $DB0_5$ is one of the parameters that directly affects the water quality index. The TC parameter presents high values at points #1 and #3, as an effect of the discharge from the Dry River channel and the presence of settlements and homes of street dwellers who perform their physiological needs directly in the river. Point #6 shows a 47 % increase in BOD_5 concentration due to the reception of domestic discharges.

As parameters such as TC and BOD_5, are determinant in the ICACOSU of 7 variables, managing to decrease the values from the Bad to Very Bad classification category in the last two monitoring points, these

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

are very important to adequately measure the water quality since they show a more real result and according to the state in which the effluent is found.

Although the SDA, in agreement with the Los Andes University, performs the pertinent modeling (QUAL2K and mass balances) to establish the water quality objectives for the district in 4 and 8 years, the values found exceed the values established by regulations, and only points #2 and #3 comply with most of the parameters in the maximum limits, being CT a parameter that is not complied with, as mentioned, mainly due to the existence of street dwellers and the discharge of untreated sewage from the homes of the localities surrounding section 3 of the Fucha River.

It is important to establish quality objectives for the urban river contextualized in the realities of the study area, which will show the existing possibilities to reduce the pollutant loads of both domestic and industrial discharges that reach the river, as stated in the PSMV; otherwise, it will not be possible to comply with these objectives. It should be noted that the maximum limits established in relation to, for example, the DO values are values that do not stimulate the recovery, self-purification and ecological development of the basin, understanding that it is a river and not a wastewater drainage channel.

As confirmed by Tiburcio and Perevochtchikova (2020), in their work on indicators for water quality in Mexico City, in which they state in relation to the quality of water in surface bodies, the values obtained are classified from Very Polluted to Polluted, according to Conagua, a situation promoted by the piping of rivers and mixing with wastewater, so the city of Bogotá must work on the city's wastewater management system so that this does not affect the quality of water in urban rivers.

The water quality situation is no different for water sources in rural areas with water supply use, as mentioned by Trujillo-Zapata, Cortés-Orozco, Vinasco-Guzmán, Ortega-Astudillo and Cruz-Ospina (2020), when concluding that despite the high contrast between the upper part of the Guahicos River (Colombia), very close to the natural reserve area, with the presence of riparian forest and less direct discharges of domestic water, and the lower part of the river, with the absence of riparian forest, surrounded by the population settlement and receiving more direct discharges of domestic water, with the presence of riparian forest and less direct discharges of domestic water, and the lower part of the river, with the absence of riparian forest, surrounded by the population settlement and receiving more direct and indirect discharges, the variation of the WQI is almost nonexistent. Rivers are used as drainage channels without concise basic sanitation plans to prevent water resource degradation.

Conclusions

Urban rivers are recipients of wastewater from homes and industries, so maintaining water quality as it flows is utopian, if strict control measures are not established for the water sources or if the channels for wastewater and those for rainwater are not managed in a discriminate manner. It is important to highlight that the quality of the river tends to improve if it

Tecnología y ciencias del agua, ISSN 2007-2422, 14(5), 291-330. DOI: 10.24850/j-tyca-14-05-07

has a ZMPA that helps to maintain the condition of river to the water body, since the channeling and discharge of wastewater does not allow the river to be treated as such, the UPZs that have interaction with the river should seek to open spaces for conservation land use in the river's banks.

The ICACOSU for dive variables (DO, TSS, COD, EC and pH) determined that for points #1 and #2, the water quality was categorized as **medium**, while monitoring points #3, #4, #5 and #6 reflect a **bad** water quality, due to domestic and industrial discharges into the canal from the city's public sewage system, in addition to the interception of the Comuneros channel with discharges high in organic matter that further deteriorate the quality of the river and prevent aquatic life from developing or being used for any type of activity such as agricultural and/or domestic use.

The ICACOSU for 7 variables (DO, TSS, COD, EC, pH, BOD and TC) as a result of the analysis obtained for monitoring points #1, #2, #3 and #4 a **bad** water quality index, and for sampling points #5 and #6 a **very bad** water quality, this behavior was mainly due to the fact that the TC parameter showed very high values above the maximum values allowed by Colombian regulations (2 000NMP/100 ml).

Compliance with the water quality objectives established in Resolution 5731 of 2008 with respect to section 3 of the Fucha River for the year 2020, the parameters OD, BOD_5, COD, TSS, TC and pH were evaluated, of which only COD and pH comply with the values established in the aforementioned standard, with the highest non-compliance values being CF and TSS (SDA, 2008b).

The results obtained give an X-ray of the state of the Fucha River in section 3 in relation to the fulfillment of the quality objectives to be met by 2020, It is also discouraging that the values proposed as quality objectives do not tend to preserve the river as a river but as a drainage channel, as evidenced by the ICACOSU values of Bad and Very Bad in items #5 and #6.

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